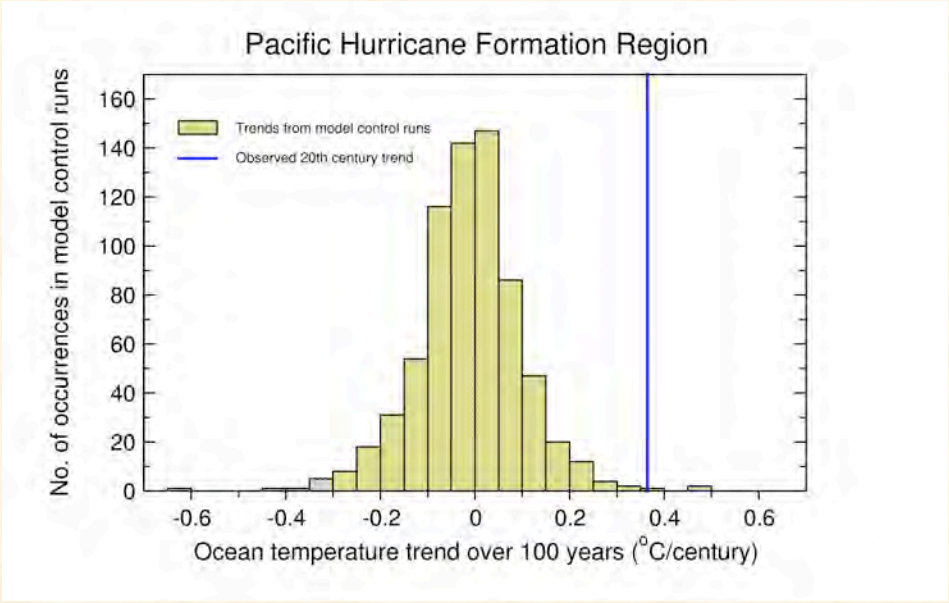
Recent Advances in Detection and Attribution Studies

Ben Santer[1], Tom Wigley, Tim Barnett, Celine Bonfils, Jerry Meehl, Dave Pierce, Claudia Tebaldi, Mike Wehner

[1]Program for Climate Model Diagnosis and Intercomparison
Lawrence Livermore National Laboratory, Livermore, CA 94550

Peter Gleckler, Krishna AchutaRao, Jim Boyle, Wolfgang Brüggemann, Phil Duffy, Mike Fiorino, Nathan Gillett, Jim Hansen, Phil Jones, Steve Klein, Jerry Meehl, Sarah Raper, Dick Reynolds, Karl Taylor, and Warren Washington

Third Annual Climate Change Research Conference
Sacramento, Sept. 14th, 2006



Structure of talk

- Detection and attribution: A brief primer
- Recent progress in detection and attribution ("D&A") research
  - Robustness and consistency of D&A results
  - The great MSU debate: A resolution?
  - Detecting human effects on climate at regional scales
  - Assessing risks of changes in extreme events
- Conclusions

Detection and attribution defined

- *Detection of climate change*
  - The process of showing that an observed change is highly unusual in a statistical sense
  - An analogy is the “detection” of a fever by measuring the body temperature
- *Attribution of climate change*
  - The process of establishing cause and effect relationships
  - An analogy is diagnosing the cause of the fever through a complete set of medical tests

Why is detection and attribution work important?

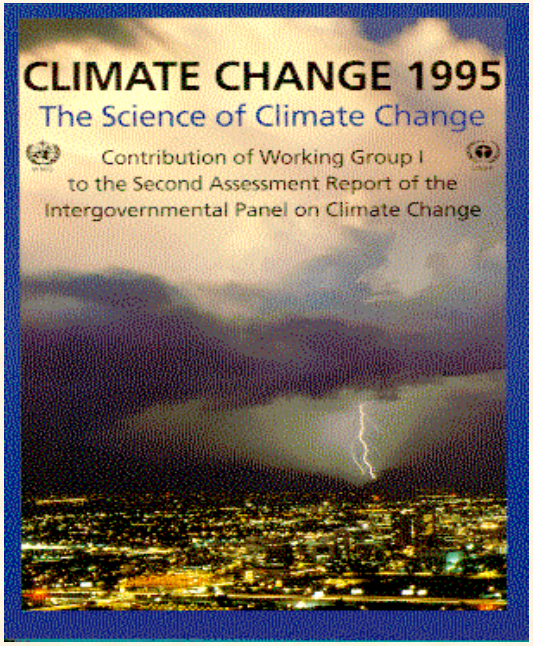
- It is a form of model evaluation
- Successful simulation of historical changes in climate enhances confidence in projections of future climate change
- In an environment where there is still political debate regarding the reality of a human effect on global climate, it is imperative to have “sound science” on the nature and causes of climate change

Detection conclusion of IPCC First Assessment Report (1990)

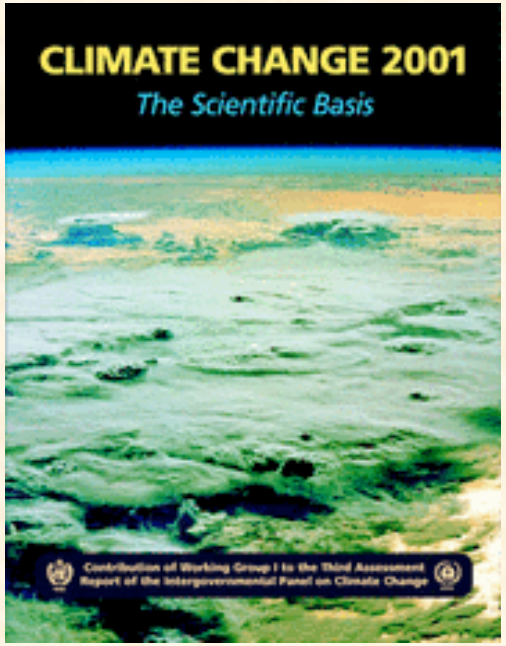
"The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more, when the commitment to future climate change will then be considerably larger than it is today".

Source: Climate Change: The IPCC Scientific Assessment. Policymakers Summary, IPCC Working Group I Report, page xxix, 1990

Detection and attribution conclusions of IPCC Second and Third Assessment Reports (1995, 2001)



"The balance of evidence suggests a discernible human influence on global climate"

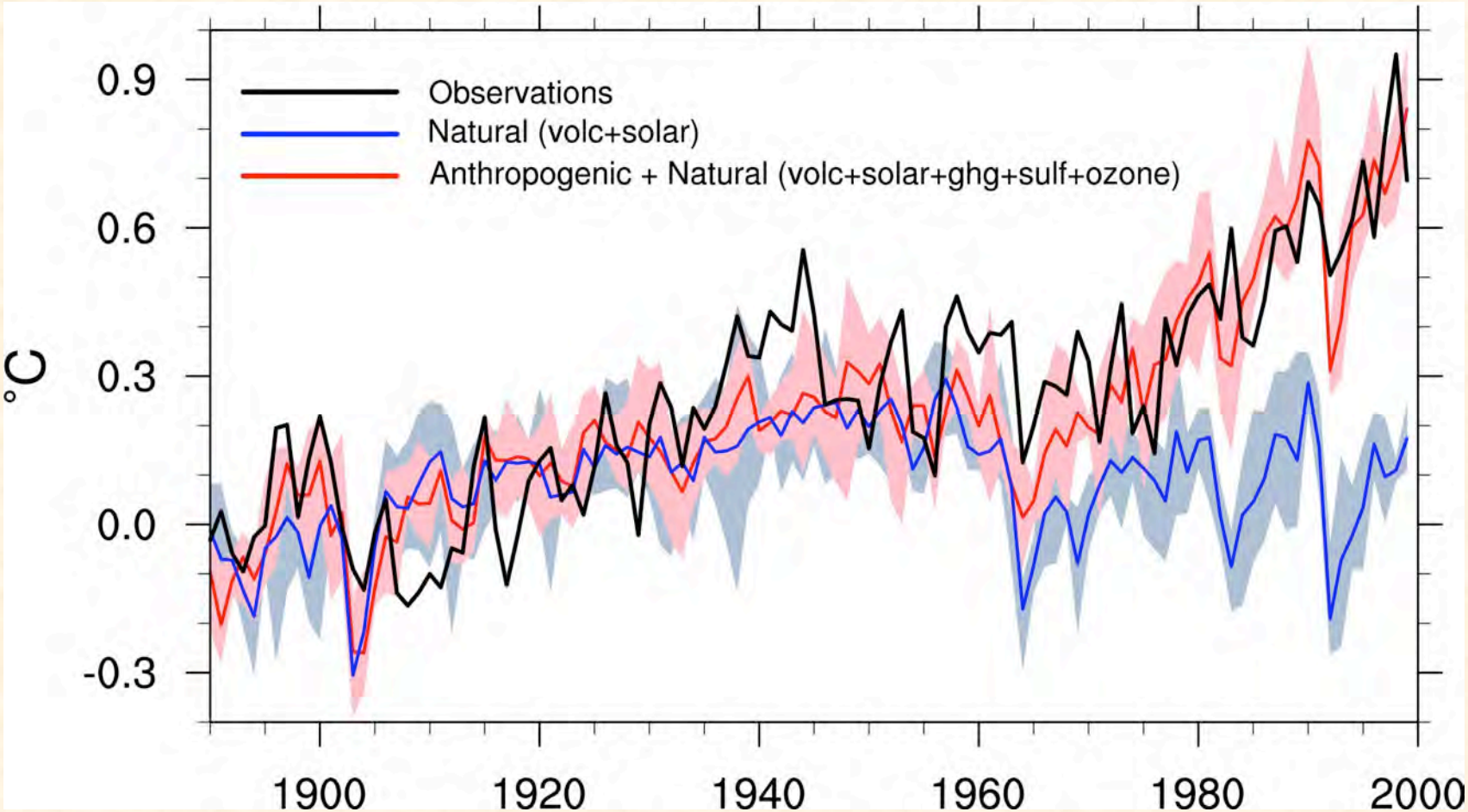


"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities"

Types of evidence in climate change studies

- *Circumstantial: Qualitative agreement between models and data*
  - Warmer temperatures
  - Reduced sea ice
  - Increased rainfall at high latitudes
- *Paleoclimatic: Comparisons between past and present climate*
  - Evidence from reconstructions of temperature (tree rings, ice cores, corals, borehole temperatures, *etc*.)
- *Fingerprinting: Formal statistical comparisons between models and data*
  - Comparison of modeled and observed patterns of climate change

Computer models can be used to separate natural and human effects on climate



Meehl *et al.*, *J. Climate* (2004)

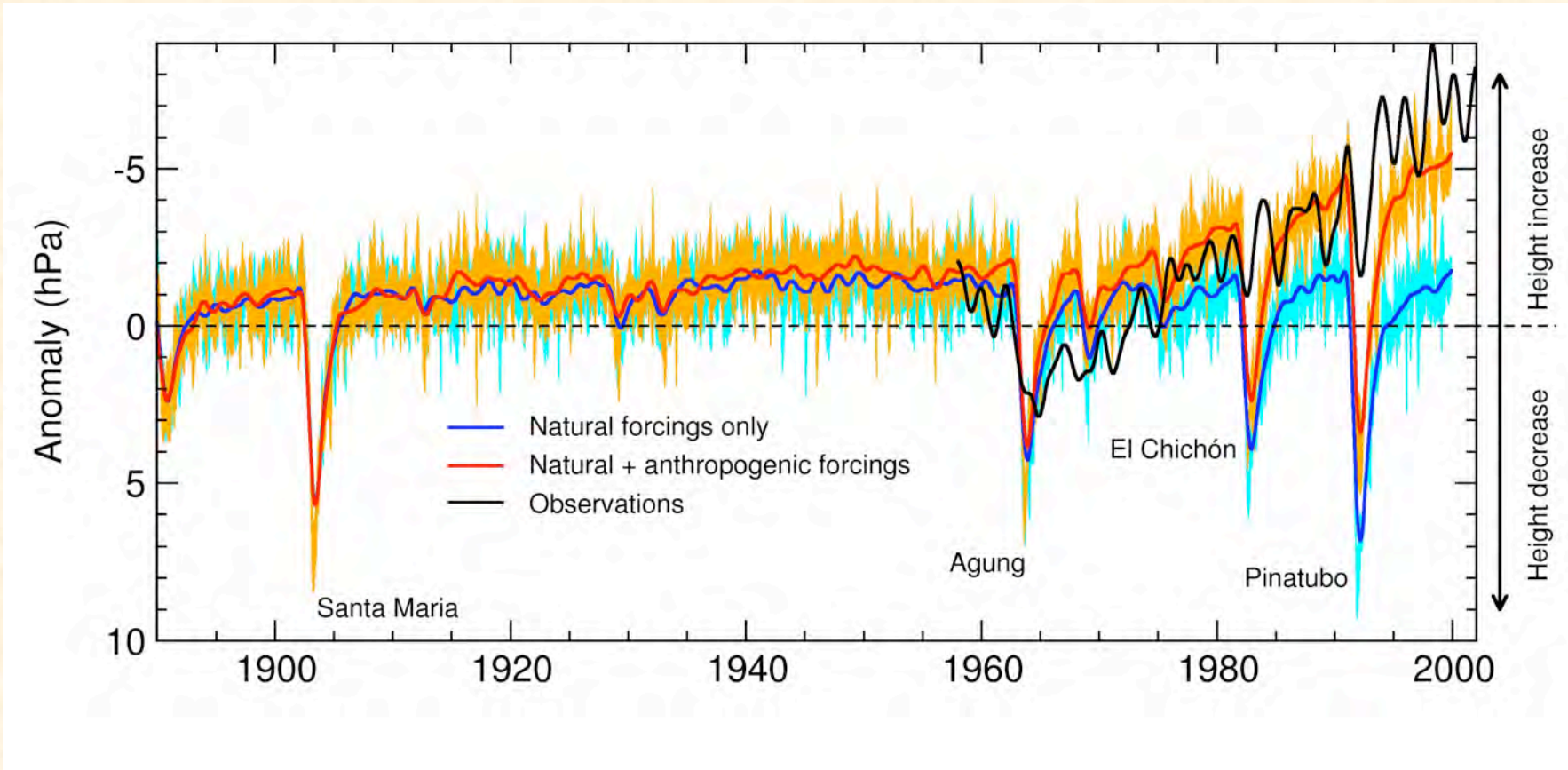
Structure of talk

- Detection and attribution: A brief primer
- Recent progress in detection and attribution ("D&A") research
  - Robustness and consistency of D&A results
  - The great MSU debate: A resolution?
  - Detecting human effects on climate at regional scales
  - Assessing risks of changes in extreme events
- Conclusions

Robustness of fingerprint results

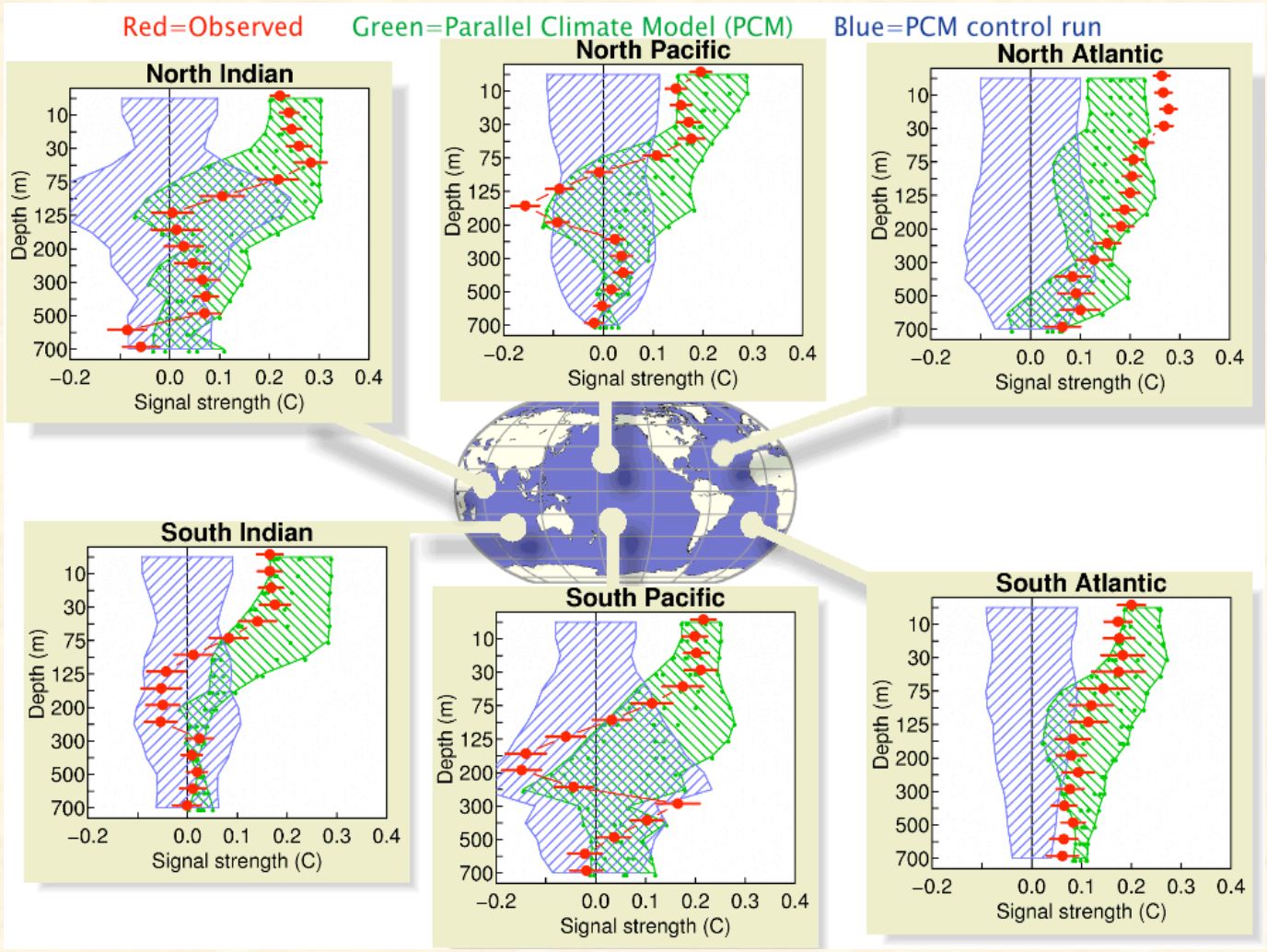
- Fingerprinting involves research groups around the world
  - *Examples:* Canadian Climate Centre, Climatic Research Unit, GFDL, Hadley Centre, JPL, LLNL, MIT, Max-Planck Institute for Meteorology, NCAR, Oklahoma State University, Oxford University, Scripps, Texas A&M University
- Groups have used a wide variety of statistical methods, observational data sets, and climate models
- Fingerprint techniques have been successfully applied to a range of different climate variables
  - *Examples:* surface temperature, vertical profiles of atmospheric temperature change, ocean heat content, sea-level pressure, tropopause height
- Bottom line: Natural climate variability alone cannot explain the observed climate changes over the second half of the 20th century

Fingerprint evidence: Changes in the height of the tropopause



Santer *et al.*, *Science* (2003)

Fingerprint evidence: Warming of the world's oceans over 1955-99



Barnett *et al.*, *Science* (2005)

Structure of talk

- Detection and attribution: A brief primer
- Recent progress in detection and attribution ("D&A") research
  - Robustness and consistency of D&A results
  - The great MSU debate: A resolution?
  - Detecting human effects on climate at regional scales
  - Assessing risks of changes in extreme events
- Conclusions

We have made progress in resolving an important problem: The apparent lack of tropospheric warming

"…satellite measurements over 35 years show no significant warming in the lower atmosphere, which is an essential part of the global-warming theory".

James Schlesinger (former U.S. Secretary of Energy, Secretary of Defense, and Director of the CIA), "Cold Facts on Global Warming", L.A. Times, January 22, 2004

Three recent papers in *Science* shed light on "differential warming"

The Effect of Diurnal Correction on Satellite-Derived Lower Tropospheric Temperature

Carl A. Mears and Frank J. Wentz

Satellite-based measurements of decadal-scale temperature change in the lower troposphere have indicated cooling relative to Earth's surface in the tropics. Such measurements need a diurnal correction to prevent drifts in the satellites' measurement time from causing spurious trends. We have derived a diurnal correction that, in the tropics, is of the opposite sign from that previously applied. When we use this correction in the calculation of lower tropospheric temperature from satellite microwave measurements, we find tropical warming consistent with that found at the surface and in our satellite-derived version of middle/upper tropospheric temperature.

An early satellite-based analysis of the temperature of the tropical troposphere has a spurious cooling trend

Radiosonde Daytime Biases and Late–20th Century Warming

Steven C. Sherwood,[1]* John R. Lanzante,[2] Cathryn L. Meyer[1]

The temperature difference between adjacent 0000 and 1200 UTC weather balloon (radiosonde) reports shows a pervasive tendency toward cooler daytime compared to nighttime observations since the 1970s, especially at tropical stations. Several characteristics of this trend indicate that it is an artifact of systematic reductions over time in the uncorrected error due to daytime solar heating of the instrument and should be absent from accurate climate records. Although other problems may exist, this effect alone is of sufficient magnitude to reconcile radiosonde tropospheric temperature trends and surface trends during the late 20th century.

Weather balloon estimates of the temperature of the tropical troposphere may also contain a spurious cooling trend

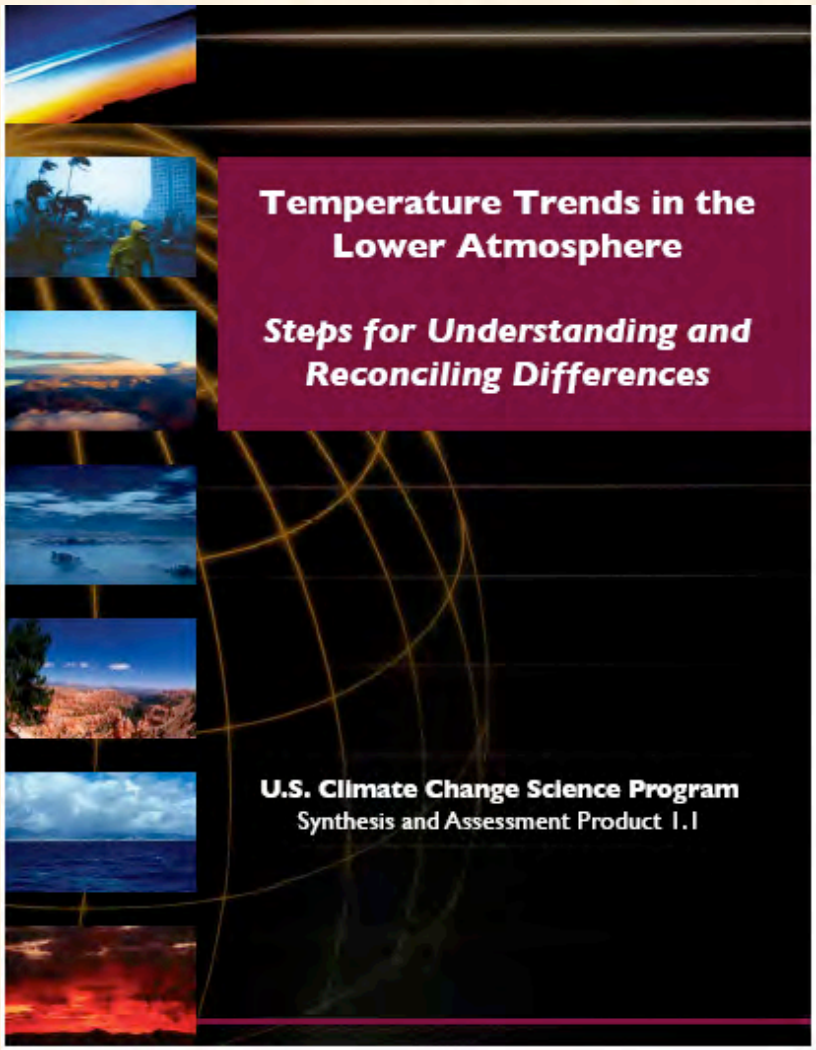
Amplification of Surface Temperature Trends and Variability in the Tropical Atmosphere

B. D. Santer,[1]* T. M. L. Wigley,[2] C. Mears,[3] F. J. Wentz,[3] S. A. Klein,[1] D. J. Seidel,[4] K. E. Taylor,[1] P. W. Thorne,[5] M. F. Wehner,[6] P. J. Gleckler,[1] J. S. Boyle,[1] W. D. Collins,[2] K. W. Dixon,[7] C. Doutriaux,[1] M. Free,[4] Q. Fu,[8] J. E. Hansen,[9] G. S. Jones,[5] R. Ruedy,[9] T. R. Karl,[10] J. R. Lanzante,[7] G. A. Meehl,[2] V. Ramaswamy,[7] G. Russell,[9] G. A. Schmidt[9]

The month-to-month variability of tropical temperatures is larger in the troposphere than at Earth's surface. This amplification behavior is similar in a range of observations and climate model simulations and is consistent with basic theory. On multidecadal time scales, tropospheric amplification of surface warming is a robust feature of model simulations, but it occurs in only one observational data set. Other observations show weak, or even negative, amplification. These results suggest either that different physical mechanisms control amplification processes on monthly and decadal time scales, and models fail to capture such behavior; or (more plausibly) that residual errors in several observational data sets used here affect their representation of long-term trends.

When errors in the satellite and weather balloon data are accounted for, both models and observations show warming of the tropical troposphere relative to the surface

Resolution



"Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human-induced global warming…. This significant discrepancy no longer exists…"

(from Preface of CCSP Report, May 2006)

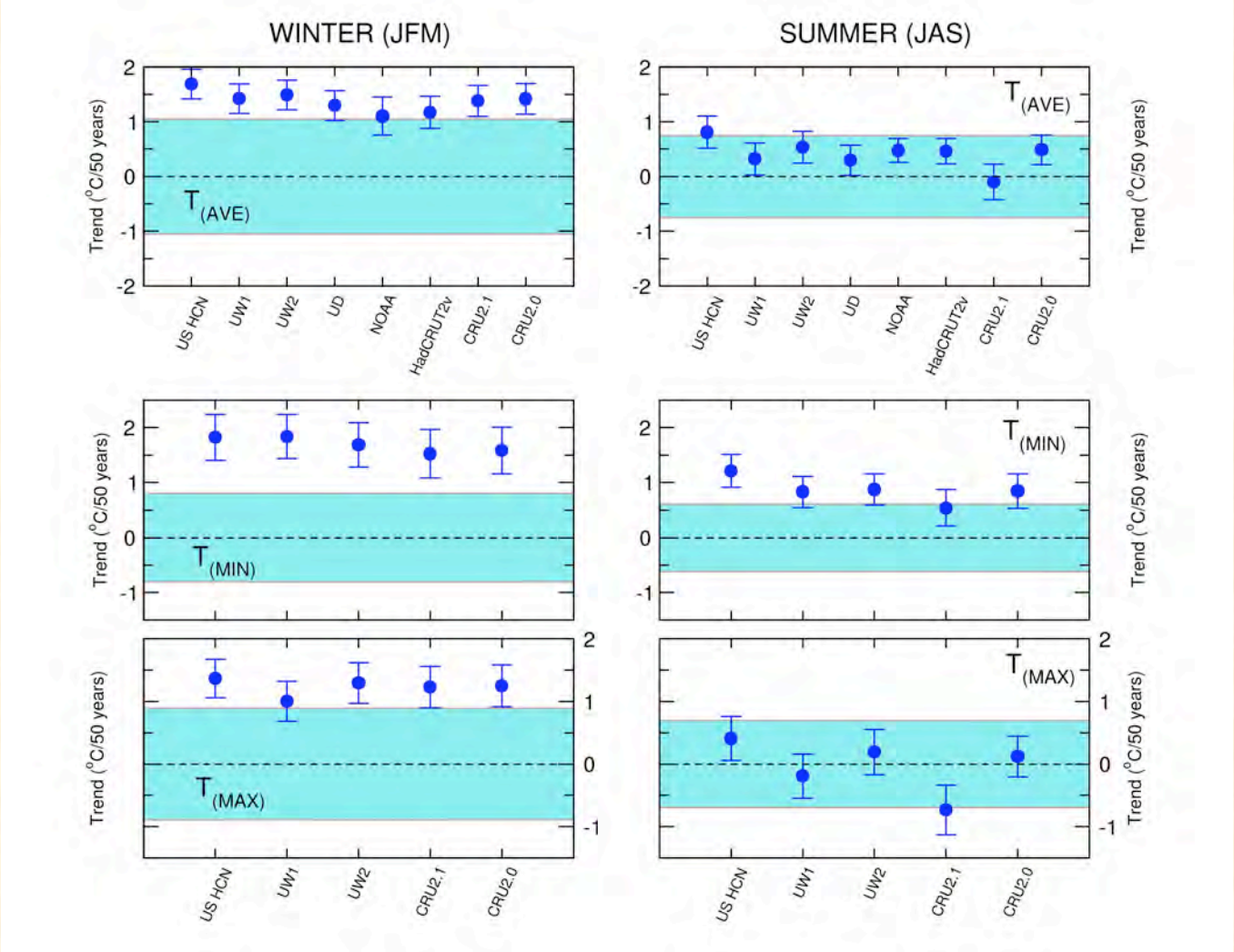
Structure of talk

- Detection and attribution: A brief primer
- Recent progress in detection and attribution ("D&A") research
  - Consistency and robustness of D&A results
  - The great MSU debate: A resolution?
  - Detecting human effects on climate at regional scales
  - Assessing risks of changes in extreme events
- Conclusions

Detecting human effects on climate at regional scales

- Two examples
  - Temperature changes over California
  - Ocean surface temperature changes in hurricane formation regions

Example 1: Wintertime temperature trends in California exceed model estimates of “climate noise”



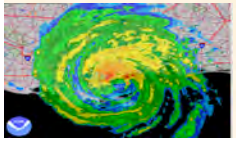
Source: Celine Bonfils (UC Merced)

Example 2: Are we changing the conditions necessary for hurricane formation?

- Theory, observations and modeling provide evidence of a link between changes in sea surface temperatures (SSTs) and hurricane intensity

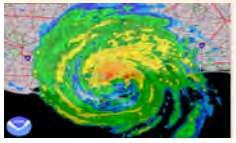
- *Emanuel* (2005) found that SST changes in ocean regions where Atlantic and Pacific hurricanes form were highly correlated with a measure of hurricane intensity

- Given evidence of links between SSTs and hurricane intensity, what are the causes of past SST changes in areas where hurricanes develop?



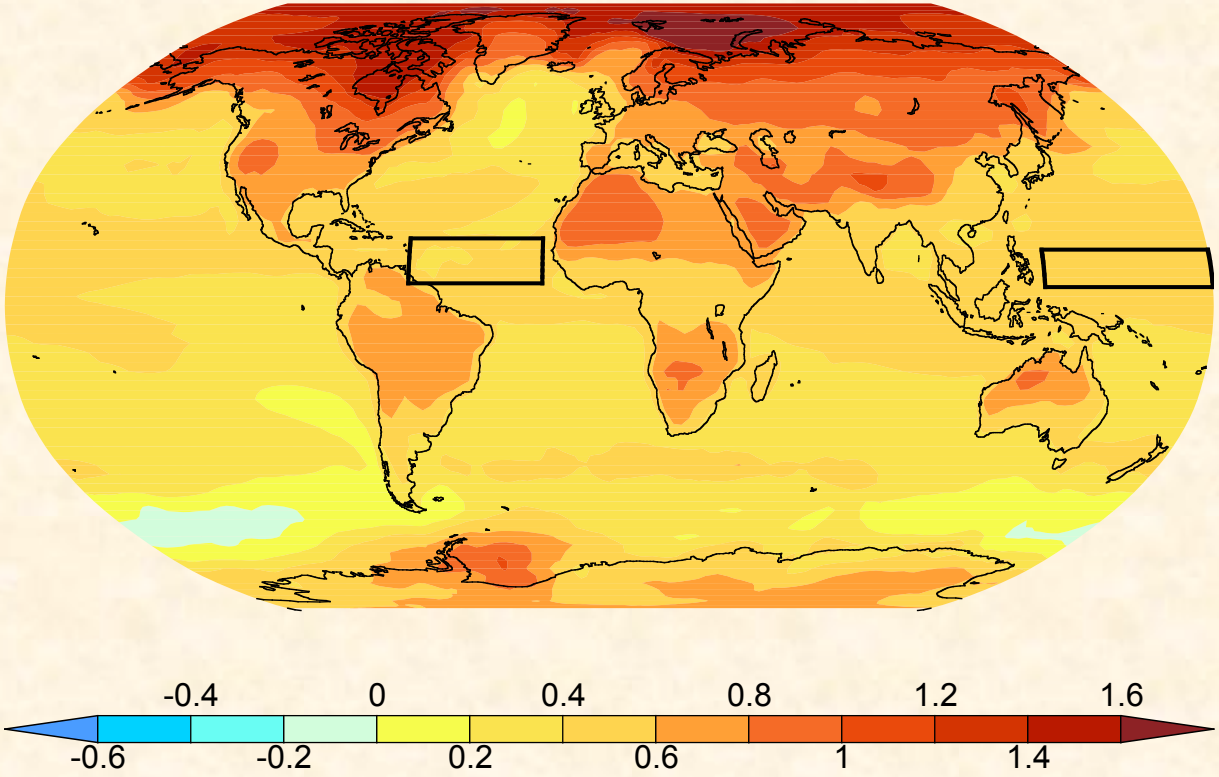
Such causality questions were unresolved

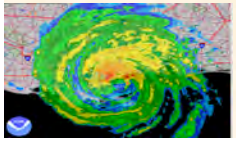
- Conflicting estimates of the relative contributions of internal climate variability and external forcing to observed SST changes
  - HYPOTHESIS I: Internal variability ("Atlantic Multidecadal Oscillation") explains all SST variability in tropical Atlantic (*Bell and Chelliah*, 2006)
  - HYPOTHESIS II: There is a substantial anthropogenic component in observed SST changes and changes in upper ocean heat content (*Emanuel*, 2005; *Trenberth and Shea*, 2006; *Barnett et al.*, 2005; *Mann and Emanuel*; 2006)



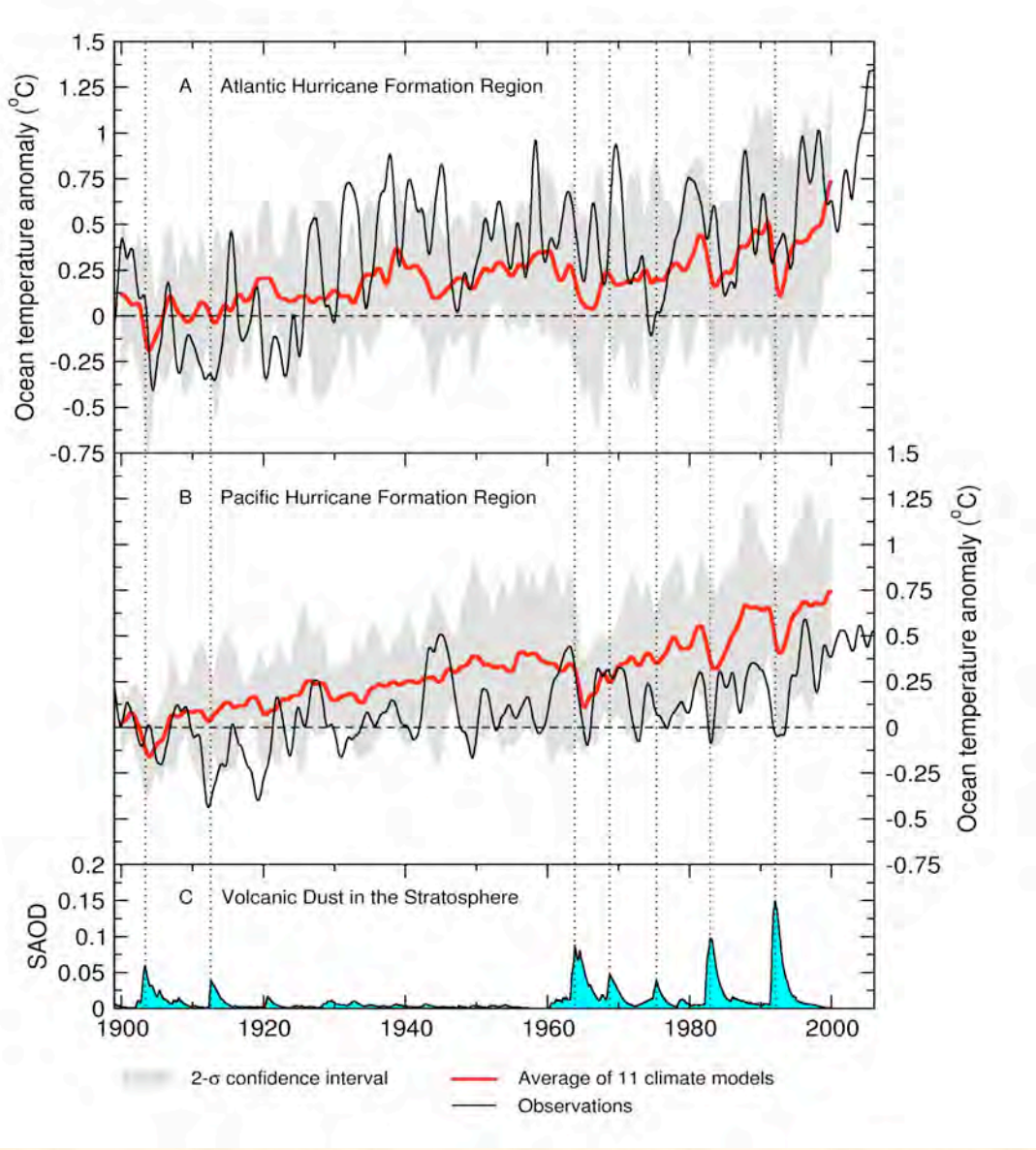
Atlantic and Pacific hurricane formation regions

Model average temperature change over 1950-99 (°Celsius)

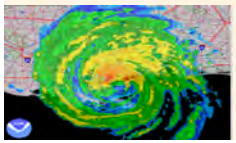




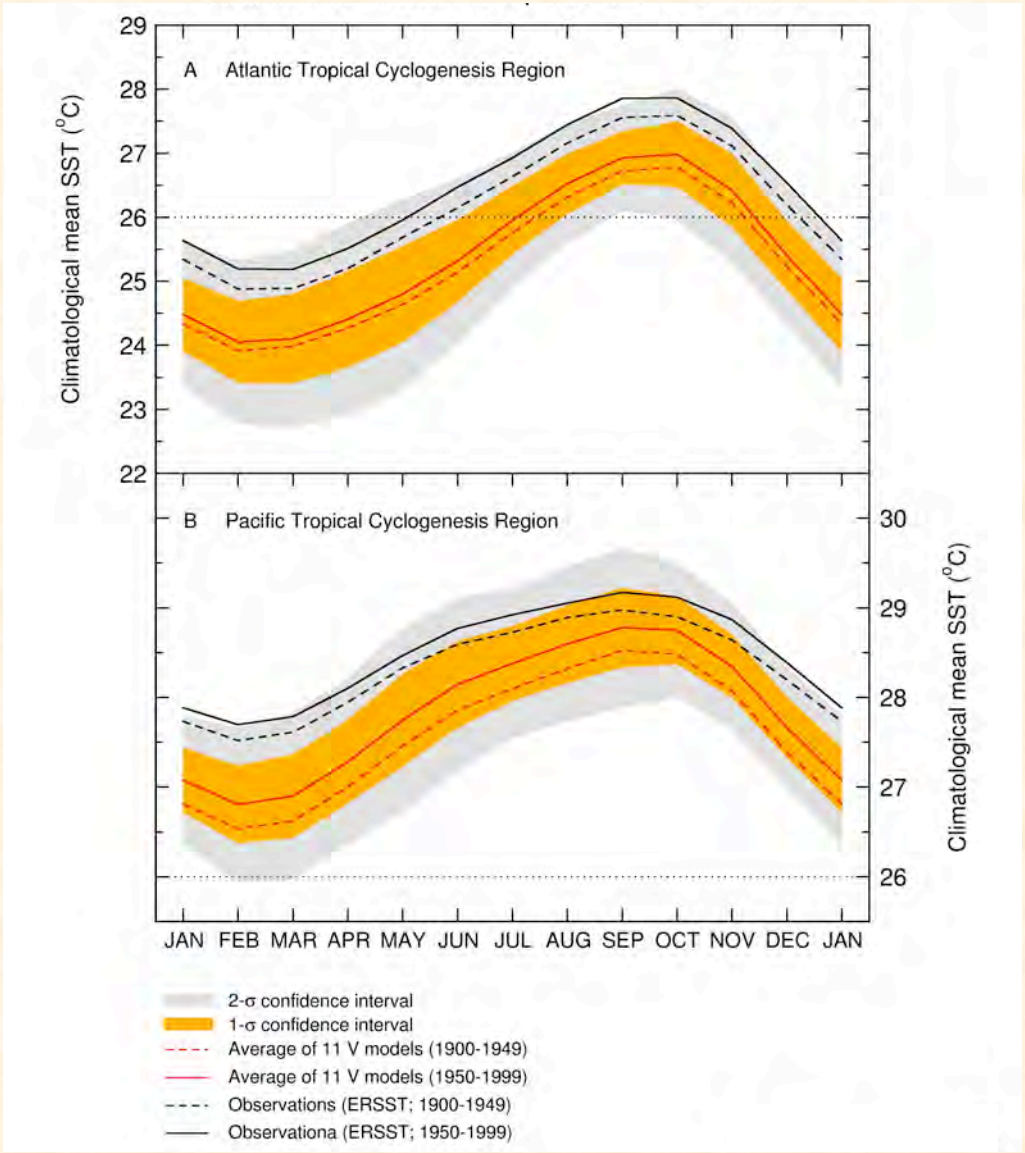
Modeled and observed ocean temperature changes in hurricane formation regions



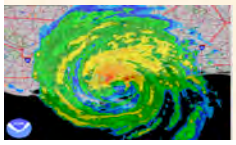
Santer *et al.*, *PNAS* (2006)



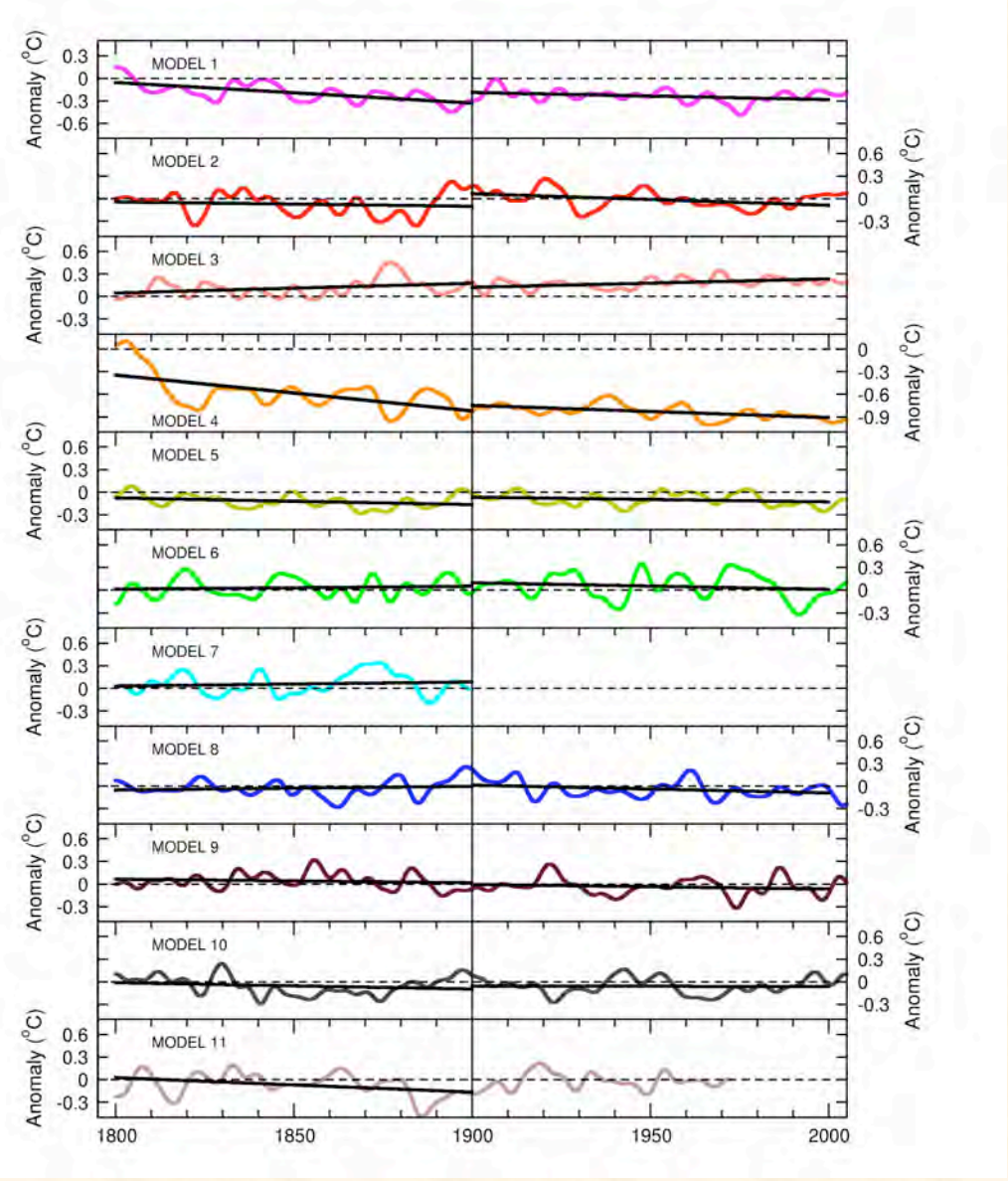
Changes in climatological seasonal cycle of SST in hurricane formation regions



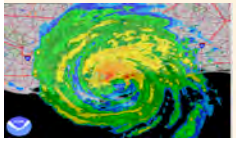
Santer *et al.*, *PNAS* (2006)



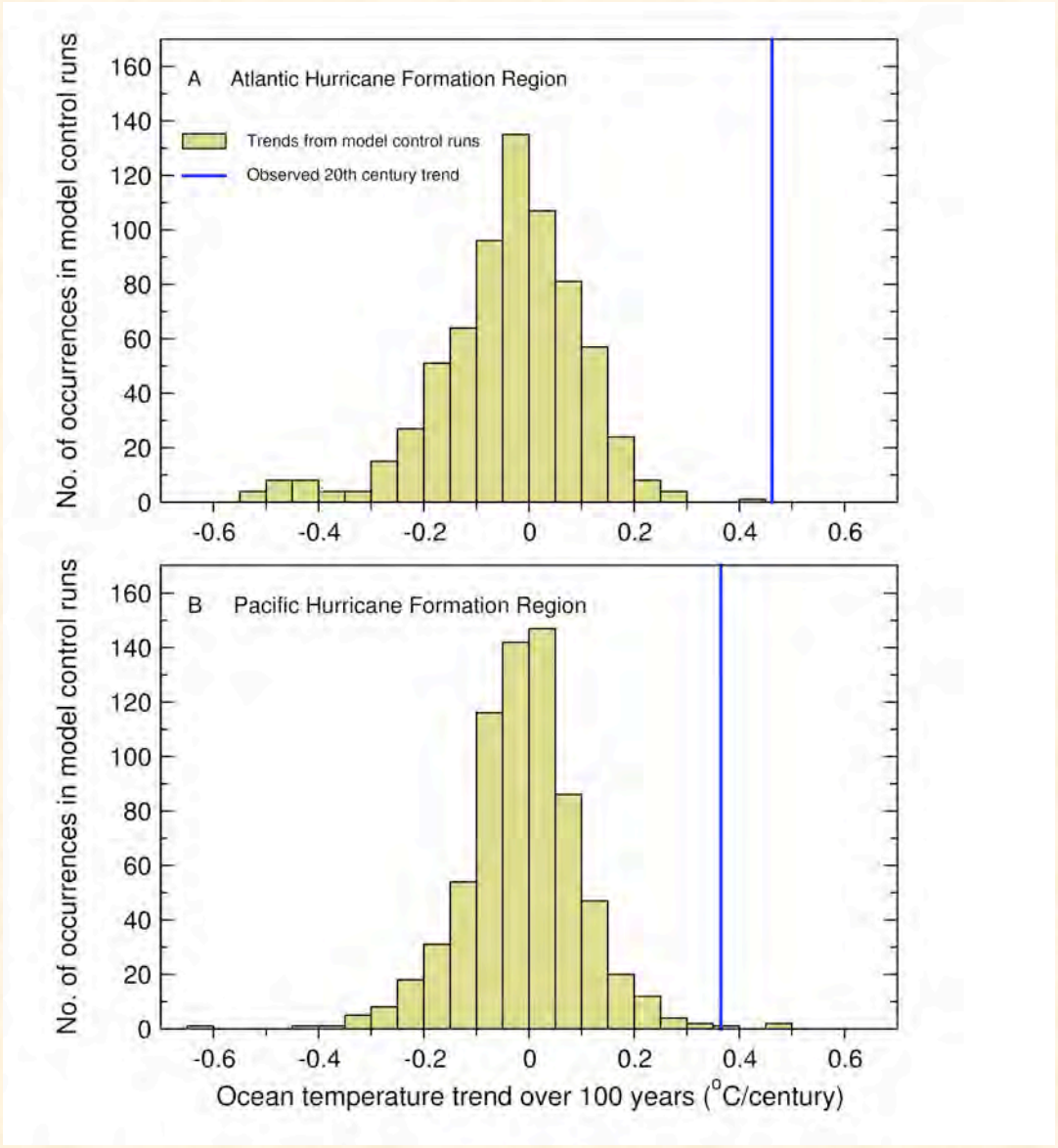
How large are “natural” ocean temperature changes in hurricane formation regions?



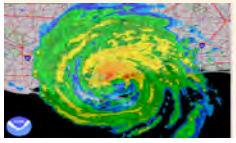
Santer *et al.*, *PNAS* (2006)



"Climate noise" cannot explain observed 20th-century trends in ocean surface temperatures

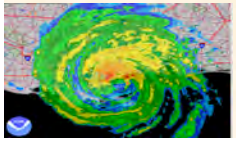


Santer *et al.*, *PNAS* (2006)

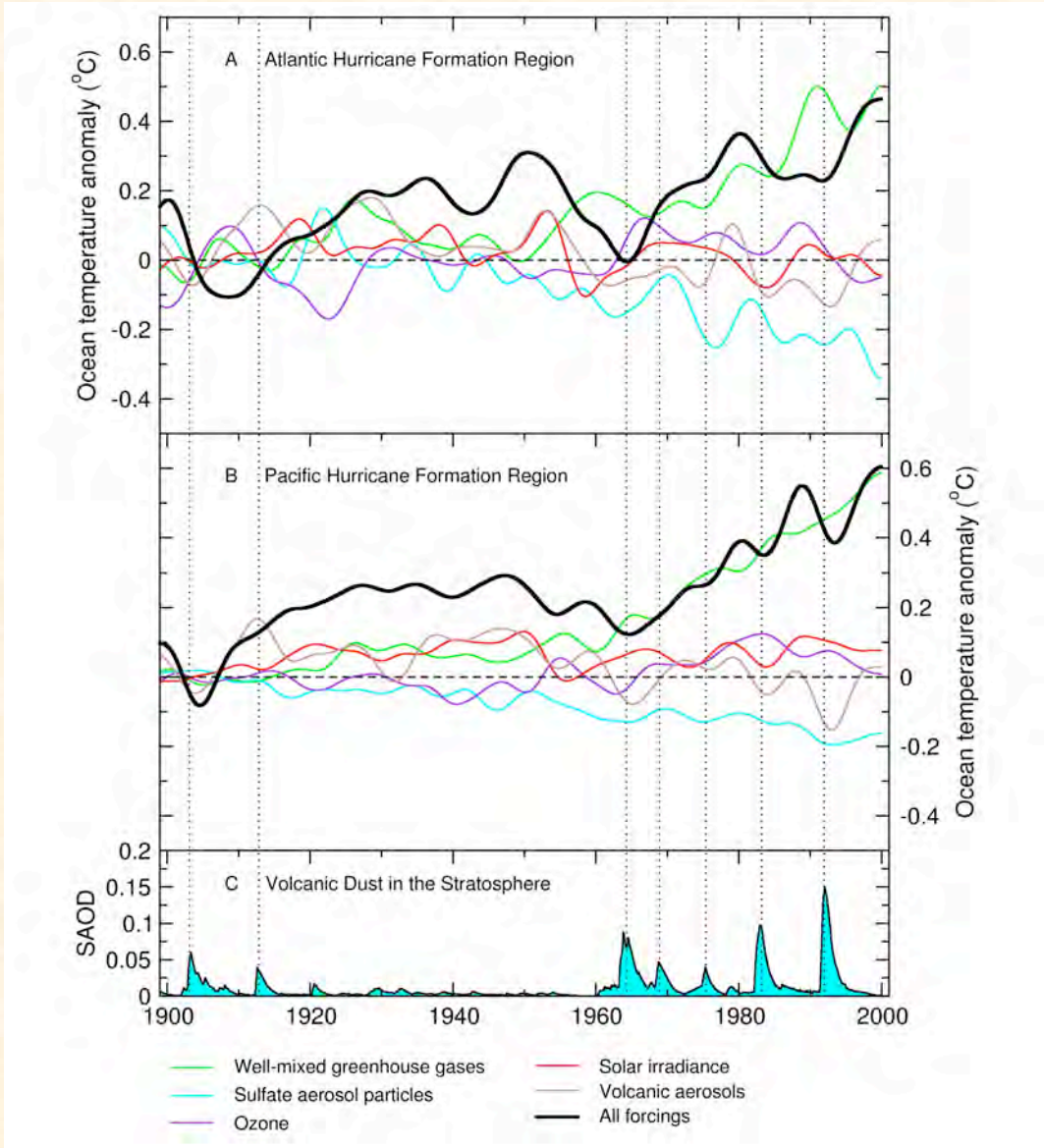


Significance testing procedure is conservative

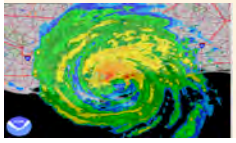
- Relies on results from many different models
- Control run drift not subtracted prior to estimation of sampling distributions of unforced trends
- Test against both actual and absolute values of unforced trends



Greenhouse gases are probably the main cause of ocean temperature increases in hurricane formation regions

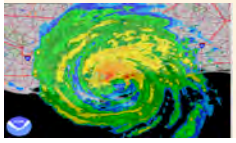


Santer *et al.*, *PNAS* (2006)



Summary of recent hurricane work (Santer *et al*., *Proceedings of Natl. Academy of Sciences*, 2006)

- Current model estimates of natural climate variability cannot explain 20th century SST increases in either the Atlantic or Pacific hurricane formation regions
- For the period 1906-2005, there is an 84% chance that external forcing explains at least 67% of observed SST increases
- Model “single forcing” experiments suggest that greenhouse gases have been the main influence on century-timescale SST increases



Structure of talk

- Detection and attribution: A brief primer
- Recent progress in detection and attribution ("D&A") research
  - Robustness and consistency of D&A results
  - The great MSU debate: A resolution?
  - Detecting human effects on climate at regional scales
  - Assessing risks of changes in extreme events
- Conclusions

Changes in hurricane intensity and frequency: Natural or human induced?

Watson* told The Associated Press in an interview Monday that the Bush administration does not blame global warming or climate change for extreme weather - including the hurricanes that ravaged the Gulf Coast states and much of the Caribbean and Yucatan Peninsula.

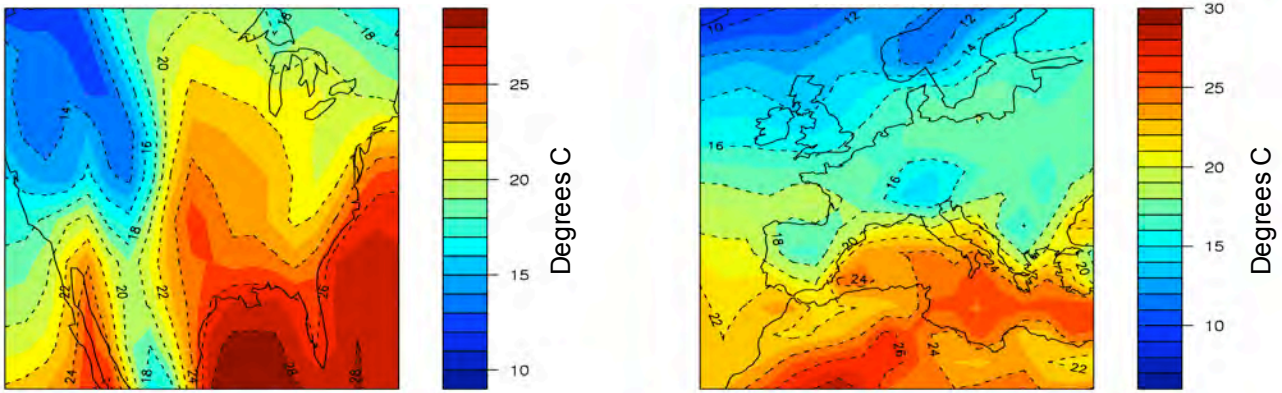
“There's a difference between climate and extreme weather,” Watson said. “Our scientists continually tell us we cannot blame any single extreme event, attribute that to climate change.”

Source: Associated Press, Dec. 1, 2005.

*Harlan Watson, “Chief climate control negotiator for the U.S. State Department”

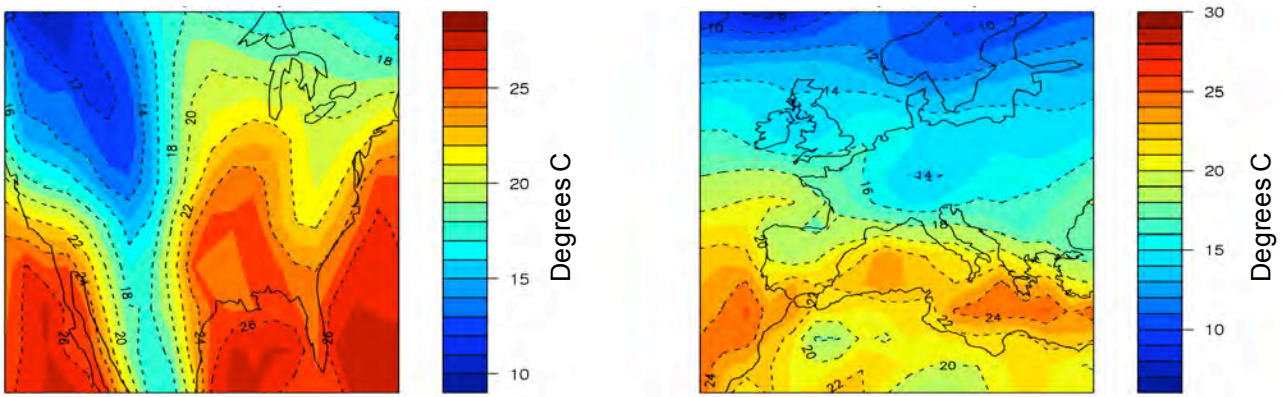
Heat waves under present-day climate conditions

Observations (NCEP): Mean of summer 3-day worst event

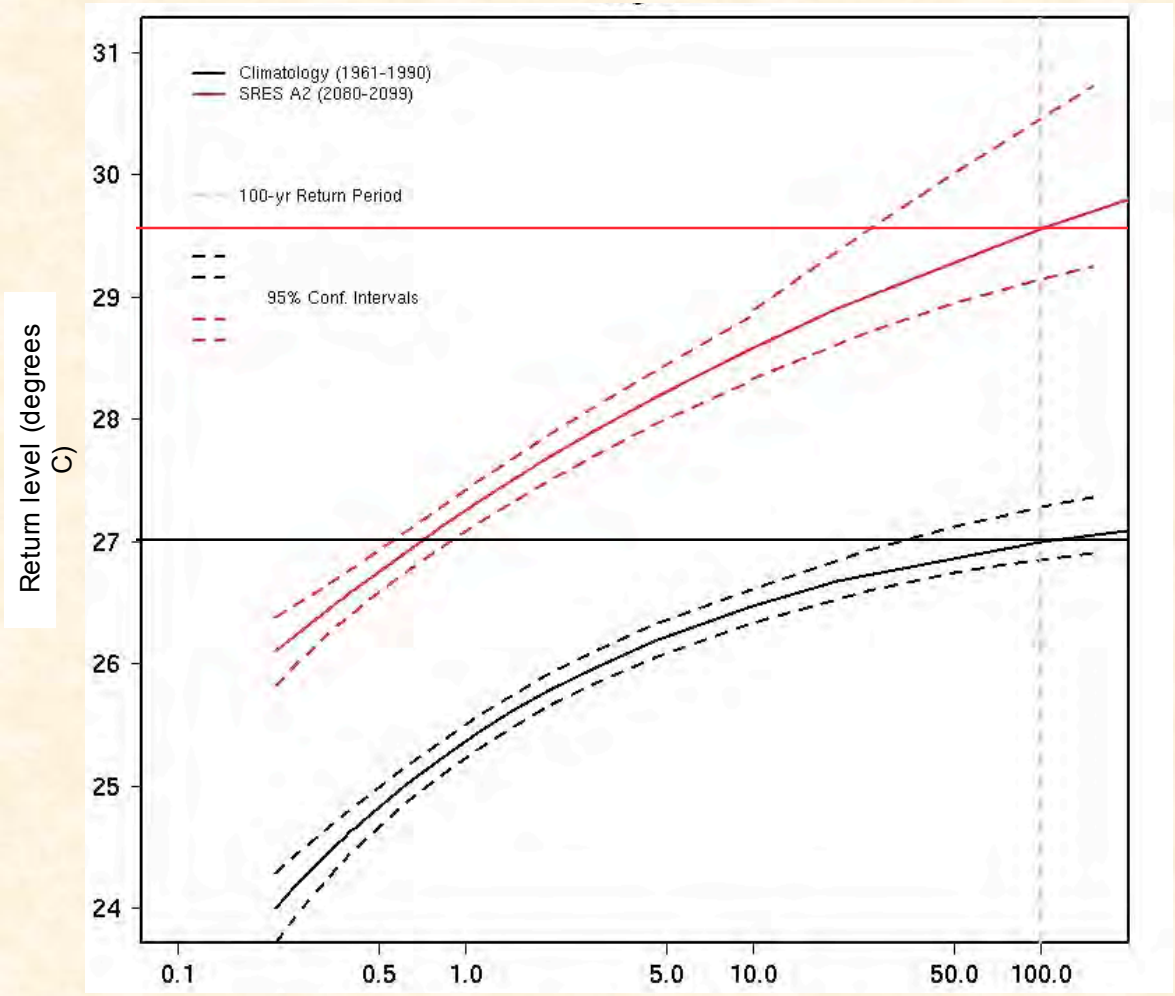


Source: Meehl and Tebaldi, *Science* (2004)

Climate model (PCM): Mean of summer 3-day worst event



Change in return period and return level for the 5 warmest consecutive summer days



Results are for average value of maximum temperature over land mass of Japan

Source: Claudia Tebaldi (NCAR)

Conclusions (I)

- Human activities have changed the chemical composition of the atmosphere, and have had an identifiable effect on global climate
- Many different “fingerprint” studies show that observed climate changes over the past 50 years cannot be explained by natural factors alone
- The most convincing explanation of observed changes involves a substantial human impact on climate
- Fingerprint results are robust and physically consistent
- There is now compelling scientific evidence that the lower atmosphere has warmed over the past 26 years
  - ➡ This removes a large stumbling block in our understanding of the causes of atmospheric temperature change

Conclusions (II)

- Large-scale warming is likely to be experienced as changes in weather and climate extremes
- It is the changes in these weather and climate extremes that will have the largest impacts on human and natural systems
- In a future warmer climate, model projections indicate:
  - More intense, more frequent and longer lasting heat waves
- We cannot confidently attribute any specific extreme event to human-induced climate change
- But we <u>are</u> capable of making informed scientific statements about the influence of human activities on the likelihood of extreme events

Conclusions (III)

- There is now emerging scientific evidence of a link between increases in sea surface temperatures (SSTs) and increases in hurricane intensity
- Computer models suggest that the observed 20th-century SST increases in the Atlantic and Pacific hurricane formation regions are primarily due to human influences
- Over the 21st century, models predict pronounced warming of SSTs in these hurricane formation regions
- This is cause for concern

We need to preserve fragile environments for future generations